CHAIRMAN'S ANNUAL DISCOURSE FOR 1899, ON THE TRANSMISSION OF ENERGY BY ELECTRICITY.

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(*Read February 3, 1899.*)

Gentlemen :—According to the old Rules of Administration and Order of the American Philosophical Society held in Philadelphia for the Promotion of Useful Knowledge, it was specified that some time during each year the President of the Society was expected to "deliver a discourse on some literary or scientific subject, accompanied by such suggestions with regard to the affairs of the Society as he shall judge proper." By the new rules, recently adopted, a date has been fixed for this discourse, with the further proviso that the President be authorized at his option to appoint one of the Vice-Presidents to take his place in carrying out the purpose of the rule. On January 14 of this year I received notice from our respected President that he had appointed me to this duty. I have selected as the subject of my discourse "Electricity as Applied to the Transmission of *Energy*," for a reason to be presently explained.

When the late Dr. William Pepper was elected a Vice-President he made much personal effort to excite an interest among the resident members in a scheme of quarterly meetings to be devoted to subjects of acknowledged importance, at which meetings a paper or papers on a subject selected for discussion should be presented, and a further effort made to insure the presence of, or correspondence from, all members who had given thought to the subject selected. He called on me soon after his election to induce me to prepare a paper on the transmission of *power* by electricity, or if I preferred not to do so, to have me suggest some one capable of carrying out the idea. At that time, about two years ago, he expressed some surprise that I should consider the subject-matter not yet far enough advanced practically for intelligent presentation or discussion. I promised, however, to correspond with my personal friends interested in electrical work to secure, if possible, contributions of importance that would be acceptable under the traditional requisites of matter fitted for our PROCEEDINGS or our *Transactions.* What has been or will be accomplished in this direction remains yet to be seen. Since that time the Society has seen fit to honor with membership many men of distinction in electrical engineering in its broadest sense. From some of these we may expect contributions.

Inasmuch as the founder of this Society, Dr. Benjamin Franklin, attracted attention as a scientist in the domain of natural philosophy by and through his electrical experiments, I think it advisable to call attention to the limited resources at his command, not only when he announced his belief that electricity and lightning were one and the same thing, but even up to the date of his death. I do so mainly to show the close interdependence between scientific research and the practical application of knowledge to the use of man, and further to show how much of the progress in exact scientific knowledge has been gained from the practical work done in experimental research by those who have not had the technical training or the knowledge of the higher mathematics, whereby they would have been able, to the extent of previously collected data, to formulate conditions leading to results in advance of the experimentation that alone can be depended on to prove the correctness of their deductions. I also desire to show how the growing wants of man have excited research, more particularly when commercial demand calls for the practical application of knowledge to any stated end.

Dr. Franklin was an experimenter. His interest in electricity as one of the then little understood but most interesting branches of natural philosophy was brought about through his ability to generate what he called "electric fire," and to exhibit the effects produced thereby, in conducting the simple experiments possible with the meagre apparatus at his command. It seems that he had received from a friend in London a glass cylinder or rod,[1] with which simple device, held in one hand and excited to produce electricity by being rubbed with a silken cloth, or the fur side of a catskin, he was able to charge Leyden jars or electric condensers, and thus exhibit the more striking effects of static electricity. The electric sparks from the outset may have impressed him as similar to the lightning flash of "thunder-storms."

In the order of chronological sequence, permit me to call attention to our records to connect this Society with his work. We know that Dr. Franklin, on April 5, 1744, eight years before his important electrical discovery, wrote to Mr. Colden explaining his idea of a Society for the Promotion of Useful Knowledge, which

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[1] This rod, in its tin case, is in the collection of the Society.

was the beginning of the American Philosophical Society. Some time between 1747 and 1750 Mr. Philip Syng[1] is credited with designing a glass globe electrical machine.[2] One of these electrical machines, in perfect order, said to have been the one Franklin made the most use of, is among the highly prized relics owned by the Franklin Institute in this city. All of us who have used electrical apparatus can appreciate the value of Mr. Syng's invention and the help it afforded to Franklin in his experiments. Franklin was, like Prof. Michael Faraday, an experimenter. Neither of these two great men possessed the mathematical habit of thought that distinguished so many philosophers before and since their time; both based all their knowledge on succcessful experiments.

In 1752 Franklin wrote to his friend in London, Mr. Collinson, expressing his grounds for belief in the identity of electricity and lightning. It matters but little now that this important letter was not deemed worth publishing in the *Transactions* of the Royal Society. Soon after it was received, however, Dr. Fothergill suggested its separate publication. Franklin's discovery thus reached and deeply interested Count de Buffon. It was translated into French, and was read by most learned men of the day. This remarkable and extensive recognition of the discovery induced the Royal Society in 1753, one year later, to make Dr. Franklin a member, without waiting for any formal application in the usual course, and without the payment of any fee or dues as a member. He was also honored the same year with the Copley gold medal for his discovery. Sir Humphrey Davy wrote of Dr. Franklin, in reference to his work, that "a singular facility of induction guided all his researches, and by very simple means he established very great truths. The style and manner of his publications are almost as worthy of admiration as the doctrines they contain. . . . . He has written equally for the uninitiated and for the philosopher."

Franklin's discovery, whether made by means of a kite in Philadelphia or by lightning rods in France, was turned to important use by his suggested protection of buildings from the effects of lightning, from "thunderbolts," or from the so-called electric fire of the clouds.

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[1] Mr. Philip S. P. Conner says that Philip Syng in Franklin's time was a goldsmith.

[2] One such globe, mounted on an axle and provided with a driving pulley, was exhibited, belonging to the cabinet of the Society.

This practical application of his discovery, taken in connection with his improvements in fireplaces, his invention, given freely to the world, of the so-called Franklin stove, and other useful inventions, are proofs of his attention to the question of practical and useful results as the outcome of his philosophical studies based on experiments. To more fully understand the limited knowledge possessed in Franklin's day, even up to his departure from life in 1790, it should be borne in mind that not until 1774, when Dr. Joseph Priestley discovered oxygen, was the chemistry of to-day possible. Priestley's discovery took atmospheric air out of the list of simple elements, and was the beginning of the rapid advance in our knowledge of chemistry. Electricity also had no acknowledged connection during Franklin's lifetime with magnetism. Aloisio Galvani had noted an effect of electricity on animals (in fact, what is now known as galvanic action) in 1780, but what is of more importance to bear in mind, in connection with the limited knowledge possessed by physicists in Franklin's time, is the invention of the voltaic pile (which was the beginning of all galvanic batteries since used), was not perfected by Alexander Volta until 1800; therefore, Galvani's and Volta's discoveries had no place in Franklin's studies.

The American Philosophical Society has among its collection some interesting pieces of apparatus of Franklin's time, but, as bearing upon this brief outline of Dr. Franklin's contribution to our knowledge of electricity, a suggestion has been made by Dr. George F. Barker, that the American Philosophical Society shall in the near future examine into the authenticity of all the apparatus held as souvenirs in America by individuals and societies which are claimed to have been used by the founder of this Society. I must also call your attention to the claim that has been made to the effect that to Dr. Franklin and Count Rumford (Benjamin Thompson), both Americans by birth, "we owe the first important step toward a full appreciation of the co-relation of forces and the conservation of energy." The limited acceptance as true of this important fundamental law of nature, based on the assumption that there is only a given amount of energy available in nature for man's use, and that no effort of human intelligence can add to or increase the amount of such energy at our disposal, is shown by the ready credence given even at this late day to the claims of inventors of perpetual-motion machines, or the ready ear lent to charlatans who, by means of verbose pseudo-scientific jargon and fraudulent exhibitions in support, claim the discovery of some new and heretofore unrecognized power that is to supersede all known forms of energy utilized in the modern means for actuating machinery.

With the first conception of the electric telegraph electricity generated by galvanic batteries was used. The energy of the galvanic battery was transmitted to instruments which produced motion and thus made visible impression upon paper, or later by sound, to convey intelligence through the equivalent of dots and dashes, or by sight noting the vibration of a needle, all of which motions involved the transmission of power, no matter how little might be required for the purpose.

When electricity came to be transmitted for lighting purposes it was not in the form of what was generally accepted as the term power, but it was the transmission of a different form of energy, one only of the many forms that are co-related one to the other. It is in the very last decade of this century that the transmission of power has come to have a meaning of greater importance than was ever dreamed of in Franklin's day, or even when Michael Faraday and others laid the foundation of the mass of valuable knowledge that was ready to be used to advantage when the needs of man called for its practical application.

It is interesting to note that although the actual transmission of power in large amounts by electricity has been carried out chiefly in the last few years, yet what is now being accomplished is the result of knowledge that was obtained quite early in the present century. Faraday's great discoveries began in 1830, and these, with what had been contributed by a host of workers before him, bore fruit before the end of the first half of the nineteenth century.

I will not take up your time with recounting the steps that led up to what forms the substance of our scientific knowledge of electricity, nor to even mention the names of the great men who have contributed to our store of information. With electricity it is very much as in the case of the locomotive, that became an established fact and an important factor in our civilization in 1827, but was anticipated and predicted by those who in a crude way operated steam carriages on common roads before that date; and long before a fairly perfect locomotive was placed upon iron rails the railroad had been demonstrated to be of advantage even with animal traction in mining operations. The iron railroad and the steam engine on wheels had to be brought together to make a perfect whole.

The beginning of this century saw in our country and by our own people the first great steps taken to make our railroad system of transportation possible through the demonstration of the advantage of using high-pressure steam. This knowledge was necessary even to make the steamboat a commercial success on the inland waters of the United States. On March 2, 1825, at the end of the first quarter of this century, refrigeration by rarefaction of air was being discussed.[1] This fact will be worth remembering when I come to speak briefly of the recent transmissions of energy by other means than electricity. Prof. S. F. B. Morse, as early as 1832, had formed an idea of his electro-magnetic system of electric telegraphing, and in 1835 he constructed his first recording telegraph instrument and used it on short distances, but it was not until 1843 that Congress, after great opposition, voted the sum of $43,000 to construct the line of communication between Washington and Baltimore, which was put in successful operation by 1844, thus giving an illustration of long-distance transmission of power to energize the magnets that gave motion to the instruments required in telegraphy. On December 16, 1848, Prof. Henry, in his second annual report to the Board of Regents of the Smithsonian Institution, proposed that so far as the funds of the Institution would permit, the magnetic telegraph be used in the investigation of atmospheric phenomena, in order that notice of the approach of storms might be given to distant observers. This was just four years after the electric telegraph had been installed.

On March 19, 1853, forty-six years ago, Prof. Henry, in an address at the close of the exhibition of the Metropolitan Mechanics' Institute at Washington, explained the true relation between power and the means at command for transmitting and utilizing power. He pointed out an error in text-books even of that late day, when elementary machines—namely, the lever, the wheel, the axle, the inclined plane, the pulley and the screw, employed separately as instruments for the application of power, or in combination as parts of complex machines—were classed as "mechanical powers," "when every tyro in science," he says, "knows they have no power in themselves; yet, through a wrong name and

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[1] See Prof. Jos. Henry's paper on this subject, read before the Albany Institute on the date above mentioned.

a misapplication of the word power, a pernicious error is perpetuated long after the fallacy is understood.'' He gave a list of what could be classed as the primary powers as used by man. ''First, water power; second, wind power; third, tide power; fourth, the power of combustion; fifth, the power of vital action,'' remarking that ''the power of volcanoes and the internal heat of the earth were as yet unused powers.'' Beyond these few, he says, ''science gives no indication of any other.'' He did not mention the direct heat of the sun as a source of power. He, however, remarked that ''Gravitation, electricity, galvanism, magnetism and chemical affinity can never be employed as original sources of power; they are at the surface of the earth forces of equilibrium, the normal condition of which must be disturbed before they can manifest power, and then the work they can do is only (approximately) equal to the power which was communicated to them in disturbing their state of rest.''

Electricity is not, he said, in itself a source of power, yet, what is very important from his point of view, ''electricity, from its extreme mobility and high elasticity, affords the means of transmitting power with scarcely any loss and almost inconceivable velocity to the greatest distance; a wave of disturbance starting from the impulse given at the battery will traverse the circumference of the earth in less time than I have been occupying in stating the fact.'' This is interesting, but we are yet far from realizing the consummation of this idea. When Prof. Henry uttered these words the electric telegraph had become a public necessity, energy had been transmitted over great distances and people had ceased to wonder.

''The telegraph,'' he said, ''could not possibly have been invented, the most ingenious synthetical mind could not have contrived the electro-magnetic telegraph, until Galvani and Oersted had made their discoveries.'' The transmission of power by electricity, however, has been possible, in varying degrees of efficiency, almost since 1832, and yet two years ago, as I said before, I felt that in its highest degree of efficiency I had not the right to say it could be presented, in a satisfactory way, to the American Philosophical Society in a manner worthy of its founder, who of all men of his day thought chiefly of the practical side of such a subject.

When Prof. Joseph Henry spoke of the possibility of transmitting an electric impulse around the globe, it was the impulse from a *galvanic battery*. No dynamo had been used in place of a battery, although instruments had been constructed to demonstrate the fact that the dynamo could be used. The electro-magnet was well understood, the electric impulse had been made to give motion to machines from electro-magnets and from permanent magnets, and the relation of the various forms of energy, represented by light, heat, magnetism, etc., were each and all known to be what has since been termed "modes of motion."

In the year 1876, marking a century in the age of our Republic, there was given to the world, through the grand Centennial Exhibition in Philadelphia, an object-lesson in the state of the arts and the advance of knowledge. The buildings in Fairmount Park, however, were not lighted by electricity, although the arc light, with clockwork to keep the carbons in proper relation to each other, was used for experimental purposes long before. As to the use of the arc light, on the 8th of December, 1858, the high light at South Foreland was illuminated by an electric current generated by one of Holmes' magneto-electric machines. In 1863 the electric light was applied to the lighthouse at La Hève, France. The chemical action of electricity was known when Carlyle and Nicholson discovered in the year 1800 that water could, by means of electricity, be resolved into its two component gases, oxygen and hydrogen, by means of the voltaic pile. Sir Humphrey Davy by the same means, seven years later, proved true Lavoissier's suspicion that the alkalies potash and sodium were not simple bodies, but compound, by the discovery of five new metals by electrolysis, viz., potassium, sodium, barium, strontian and calcium. I shall refer to one of these metals when I come to speak of the transmission of energy from one common source of power in a condition ready for use, either for turning the wheels of factories, for heating, lighting or repeating Sir Humphrey Davy's process in the production of sodium from an alkali, not as a laboratory experiment, but on a commercial scale at the rate of many tons per day.

In tracing the progress of knowledge bearing upon the transmission of energy by electricity, the United States Patent Office records furnish much information of a historical character useful for determining the chronological sequence of invention, and no more interesting chapter in the history could be obtained than that on the application of the modern dynamo by telegraph companies to supersede the galvanic batteries that for so many years supplied the electricity needed for their purpose.

There are to be found a number of patents relating to the regulation of the electro-motive force from the dynamo to equalize the pressure on lines of different lengths and different resistances. It was not, however, until lighting by electricity became a necessity in the most recent times that the great demand for electric machinery for lighting purposes, which so alarmed the gas companies, and threatened for a while even to destroy the value of the capital invested in this great branch of industry, namely, illumination by gas, became a commercial necessity. It was then that mechanical engineering talent of a high order was added to the electrical knowledge of the time to increase the efficiency of direct-current dynamos for lighting and for furnishing power in small amounts. Large establishments sprang up in Europe and in America for the manufacture of electrical machinery on an extensive scale, finally leading to the foundation of the present great corporations, whose stock is quoted among the "Industrials" listed on the Stock Exchanges of the country. Ten years ago, in 1889, these companies were doing a thriving business; yet at that time there had been little accomplished in the direction of the actual transmission of *power* by electricity, in contradistinction to the transmission of energy for lighting purposes.

I have preferred to entitle my discourse "The Transmission of Energy" rather than of "power," because the latter term serves rather to suggest kinetic energy, or the energy of matter in motion, while electricity permits the transmission of many sorts of energy. The turbine wheels at Niagara, nominally of 5000 horse power, generate kinetic energy from the water put in motion by gravity. The dynamo driven by the turbine delivers 5000 electric horse power; so efficiently is the change from kinetic to electric energy effected in this case by the dynamo that all the electric and magnetic losses in that part of the machinery amount to less than two and one-half per cent., apart from the losses due mechanical friction and windage, which are light as compared to what has been done by smaller units of power.

In the autumn of 1889 I was asked to submit a report on the transmission of power by electricity by gentlemen who had become interested in what was then known as the Evershed scheme of utilization of power of Niagara Falls, on land above the head of the

American Rapids, and above the entrance to the canal that was constructed more than forty years before to carry water from the Niagara river to factories located on the edge of the cliff, where the fall obtainable for turbines was as much as two hundred feet, though only from ninety to perhaps one hundred and twenty feet fall had been used to drive turbines. Mr. Thomas Evershed, when Chief Engineer of the State of New York, conceived the idea of locating turbines in wheel-pits sunk to a sufficient depth upon the level land above the rapids, where, under a head of sixty to one hundred feet, turbines could be operated by water carried to them through short surface canals, while the discharge from the turbines could be carried away by a tunnel serving as a tail race, this tunnel to proceed in a direct line under the city of Niagara Falls to the gorge below the falls. His scheme had been made the foundation of a charter granted to a company to construct the tunnel and such canals as might be needed for power and sewerage purposes, whereby the land on the river bank above the falls might be utilized as a manufacturing area, as at Lowell, Holyoke and other places where industries have prospered through the enterprise of the companies controlling the water privileges.

To carry out the Evershed plan involved the expenditure of very large sums of money for the tunnel and for surface canals. To effect the purpose, the Niagara Falls Power Company was organized in 1890. The Cataract Construction Company and other allied companies were started at the same time to execute the work, to improve the lands owned or controlled by those interested and to furnish transportation facilities to a large industrial district, where a uniform water power; without fear of low water or freshets, would be obtained. In the first conception of this water-power company, a central station was contemplated from which power might be transmitted to Buffalo and elsewhere, either by electricity or by some of the several modes of transmission of power already used to some advantage in Switzerland and elsewhere, where water power is abundant, coal costly and transmission for a few miles by wire rope or other means had been undertaken with marked success.

In July, 1890, I was suddenly summoned to London to confer with Mr. Edward D. Adams, the President of the Cataract Construction Company, who was alive to the great advantage of long-distance transmission by electricity, his idea being that the centralization of power and its transmission by electricity over the whole territory was feasible; hence he ordered work stopped until a careful examination could be made as to the state of the art of electricity in comparison with other modes of transmission.

To obtain reliable information on this important subject, the Niagara Falls International Commission was organized in July, 1890, with Lord Kelvin as Chairman; Prof. Wm. C. Unwin, Dean of the South Kensington Technical School, as Secretary; Prof. E. Mascart, of Paris, as representative of France, the birthplace of the modern turbine water-wheel; Col. T. Turrettini, Mayor of the City of Geneva, an engineer of great note, as representative of Switzerland, and as the engineer of the works at Geneva where power was being transmitted by water under high head; and I was appointed the representative of the United States and of the company for which the information was to be collected. By and through the work of this Commission, the opinion of engineers and engineering companies was obtained as to the best way of developing the power on the land of the company, under conditions laid down by the American company, also the utilization by transmission of the power so developed. A sum of money was paid to each competitor to cover the cost of reports, while premiums were offered to those who should present feasible schemes that could be immediately made use of for either or both of the two parts of the scheme—first, the generation of power, and, second, its transmission.

The information so gained represented the accumulated knowledge of men who could speak knowingly as to the state of the art on both of these subjects at that time. It was well worth its cost, but no perfect scheme, ready for immediate adoption and worthy of the highest premium, was presented. The Westinghouse Electric and Manufacturing Company, of Pittsburg, already interested in utilizing the alternating-current system for lighting and power purposes, having previously spent enormous sums of money to develop the alternating-current motors, generally known as the Tesla system, refused to compete on the ground that what would be offered in 1890 and 1891 could not possibly be what they might be able to submit in 1893; nor could any one suggest what would meet all the conditions which might arise during the development of the hydraulic part of their enterprise on a scale so much larger than ever before undertaken. This non-competing company, however, a few years after executed much of the work required.

A majority of the Commissioners favored the transmission by direct current, but as they were not asked to express an opinion in that direction, there was no report made as to the character of the electric current if electrical transmission should be decided upon; but a unanimous opinion was given as to the advantage of a unit of 5000 horse power for each turbine in the power house, working under a head of not over 140 feet fall, at a speed of 250 revolutions per minute, which was feasible with turbines that could be made of high efficiency.

The speed recommended was thought to be what would be acceptable to makers of dynamos, whether for alternate or direct current. It is noteworthy, as indicative of the state of the art in 1891, that out of many electrical schemes proposed all but two were based on the generation of the direct current, with the consensus of opinion in favor of the gramme ring as the type of armature.

While waiting for the reports of competing engineers to come in, between July of 1890 and the first of January, 1891, I had time to visit Italy, France, Switzerland and England, where I collected information as to the efficiency of the several modes of transmitting power at that time in vogue. I could find but one example in France of power for factory purposes transmitted by direct current, in which case a turbine was located in a rugged mountainous district, quite inaccessible in winter. The water-wheel, of perhaps 200 horse power, drove a direct-current dynamo, from which the current was conveyed by overhead conductors to a direct-current motor in a paper-mill, in a small town, a distance of five miles. This paper-mill had been operated without profit by steam, but was said to be profitable under the new conditions. The machinery in this case was started and stopped at the turbine by means of telephone communication from the mill to the men in charge at the water power. I visited many interesting plants for the transmission of power by water under pressure and by compressed air, and saw the most important electrical developments for lighting purposes, some by the alternate current, but most by the use of the direct current.

In Paris I made a careful examination of the Popp system of compressed air with great interest, on account of the highly favorable reports that had reached me and the claims as to efficiency and economy made by the projector. He even went so far as to say that in case of transmitting power from a central station to an outlying electric light plant he would use compressed air for the purpose, using air to drive the engines connected to the dynamos at the lighting stations, instead of transmitting electricity ready for immediate use. Among his various plans of using compressed air, besides operating air motors, elevators and the like, he had published a long list of uses to which it was applicable; he also submitted to the Government his cold storage scheme. In the event of foreign invasion and the investment of Paris, when local industries might be stopped, he stated that by using the compressed air from part of his compressing plant to drive the engines that operated the compressors of the other part, and utilizing the exhaust from these air-driven compressors in the Government storehouses, he could thus lower their temperature to the required degree, on the principle of refrigeration by rarefaction of air after having exerted force, as discussed by Prof. Henry on March 2, 1825, and as afterward toward 1850 used for the artificial production of ice.

The alternate-current lighting plant of Deptford, London, established in 1889, was predicated on the possible generation of electricity in large units of 10,000 volts pressure. I spent much time in watching this experiment, which was in 1891 far from meeting the expectations of its promoters. The 10,000 horse-power engines and direct connected 10,000 horse-power dynamos were never finished.

In Rome I found the most promising scheme under way to utilize the water power at Tivoli to generate a single-phase, alternate current, to be transmitted a distance of twenty-five miles to the gates of Rome by overhead cables, at a pressure of about 5000 volts, with perhaps twelve per cent. loss in transmission. The Roman plant was interesting, as in it the question of rate of alternation per second had been considered, and Ganz & Co., of Budapest, had recommended the lowest periodicity, forty-two full alternations per second, as adapted to arc and incandescent lights on the same feeders. If the rate of alternation per second be less than forty-two full periods arc lights will pulsate, while in the case of incandescent lights by alternating current the rate of alternation may be carried as low as twenty per second, depending upon the thickness of the filament, with no perceptible effect on my eyes. But in common practice seventy-two full periods per second has been adopted by electric lighting companies, as thereby the local transformers that are used to reduce, from street conductors under a pressure of 2000 volts to 100 volts in houses, are small and inexpensive; much more so than if similar machines were wound for as low a periodicity as forty-two per second. This question of period or rate of alternation per second has since come to be recognized as an important consideration in the transmission of electric energy for power purposes, and bears directly on the question of efficiency, convenience and economy in the conduct of the power-house equipment at Niagara Falls. There is so much of interest that may be said on this subject that I am loath to leave it to speak of what resulted from the study of the problems between 1890 and 1893, when in 1893 the installation of hydraulic machinery was to be begun, and an electric system adopted and put in practice ready for operation. In 1895 but one single tenant, the Niagara Falls Paper Company, now using over 7200 horse power from the surface canal of the company, was and still is the only example we have of a factory controlling its own water power directly connected to its machinery, as at Lowell and elsewhere.

During the year 1893 all idea of extending the tunnel beyond a proposed power house, and all extension of surface canal with branches to supply local factories, was given up in favor of electrical generation and transmission thereof to the users in such form as to be acceptable to the industries established on the land of the company. In the year 1893, while the greatest pressure was being exerted to induce the Cataract Construction Company to adopt the direct-current system, Mr. Edward D. Adams and the other officers of the company had before them a diagrammatic plan showing a central station for the generation of alternate-current electricity, from which conductors were figured as leading to electric furnaces, to apparatus that was capable of converting the alternate current into direct current, either by synchronous motors driving direct-current dynamos or by step-down or step-up transformers and rotary transformers that accomplished the same end. Lighting by arc and incandescent lamps was provided for, and trolley lines were designated as in operation, while an overhead pole line was figured as transmitting the energy to Buffalo or elsewhere, at any required pressure. Nothing could be more convincing than this diagram to show the elasticity of the alternate current, which was confirmed by a practical exhibition offered at Pittsburg by the Westinghouse

Company, and later a similar exhibit was given at Lynn, Mass., by the General Electric Company, the former by bi-phase generation and transmission, the latter by tri-phase.

After a most careful study of the subject from a scientific and commercial point of view, the bi-phase system of twenty-five alternations per second was adopted by the Cataract Construction Company. When such a low rate of alternation was discussed, it was apprehended that the cost of static transformers would be so much increased as to more than counterbalance the efficiency promised by the lowering of the rate of alternation; but, as in many other cases, when a want is felt, the urgency of the want leads to improvements that entirely change the conditions; so in this case, while many predicted that static transformers of this low period would cost from fifteen to twenty or even twenty-five dollars per horse power, still when tenders were to be solicited a guarantee had been exacted that the price should not exceed five dollars per horse power, while in actual practice, in healthy competition, the machinery for the purpose was secured at a very much lower rate.

As to the results reached by the system adopted, I must call your attention to the remarkable character of the industries that clustered about the central station. In 1893 there were no bi-phase motors of high efficiency manufactured, as up to the last few years alternate-current electric lighting plants had not been adapted to the operation of highly efficient motors to take the place of steam engines. There were few if any applicants for power to drive machinery. No cotton mills or other textile industries sought cheap power when it involved the use of machinery that had yet to be perfected. Existing direct-current motors could be had in abundance, but manufacturers had not yet used them. The largest cotton or woolen mills required not over 1000 horse power to drive them, while most are on a smaller scale.

The advantages offered by the elastic electric system at Niagara Falls attracted industries that employed few hands, needed little machinery, but required enormous amounts of power, which, at a lower cost than steam and without an investment in engines and dynamos, could be used profitably.

The Pittsburg Reduction Company, engaged in the extraction of the metal aluminum from its ores, was the first applicant for 1500 to 3000 horse-power electric current from the new power-house. This process, known as the Hall process, required heat energy to melt the cryolite to form the bath in the electric furnace, and a direct current of low voltage to exercise electrolytic energy in separating the metal from bauxite, which is rich in aluminum. Another enterprise, the Carborundum Company, called for 1000 horse power, in alternate current of one phase only, for a process in which heat energy alone is needed to produce a new mineral next in hardness below the diamond. So with the manufacture of carbide of calcium from coke and lime, great heat alone needed was obtainable by alternate current. The Matheson Alkali Company, making caustic soda from common salt, needed no heat energy, but over 2000 horse power of direct current for electrolytic or electro-chemical energy in a cold process to separate the chlorine gas from the salt water, the gas being delivered into enormous lead-lined chambers, the floor of each chamber being covered with lime, enabled twenty-five tons per day of bleaching powder to be furnished to the market, while the caustic soda liquor, freed from chlorine, is concentrated by boiling in iron kettles to evaporate the water and thus leave caustic soda in solid form when cold. This caustic soda, delivered to still another factory near at hand, is by a direct current, furnishing heat and electrolytic energy, made to yield pure metal sodium, just as Sir Humphrey Davy did when, with the current from a galvanic battery, he produced and gave to the world a few ounces of the new metal. The ingots of sodium, as made by the Chemical Construction Company, at Niagara Falls, are dipped into coal oil and thrown into tin cans, to be closed air-tight, ready for the market, or at once, by a simple process, converted into peroxide of sodium, one of the most powerful oxidizing reagents required in the arts. Factory after factory has been added, for various electro-chemical processes, while the establishments first started have grown in size calling for power in a rapidly increasing ratio.

While these industries were developing, electricity has been furnished to the lighting station to replace steam as the motive power, and a direct current is being delivered to the trolley lines of Niagara Falls and Buffalo. By the time the development was in shape to offer power to Buffalo, and the cost of installation was being worked out there, one great advantage of the tri-phase system over the bi-phase that had been adopted was urged as an important argument against what had been done. This advantage comes from the fact that the bi-phase transmission needs four cables, two for each phase, while the tri-phase system is worked with three cables only, each of the three cables being no larger than each of the four demanded by the bi-phase system. This advantage had been taken into consideration, but other economies incident to the bi-phase had overbalanced the question of saving in copper in the line. Before the line to Buffalo could be built, however, and as a striking instance of an urgent need of exciting the talent of inventors to supply the want, Mr. C. F. Scott, of the Westinghouse Company, startled the electricians at a meeting in Washington with his scheme of converting the bi-phase current into a tri-phase in the static transformers that are used to raise the electro-motive force of the current from 2200 volts to 11,000 volts or more—this without adding one dollar to the actual cost of the transformers needed, and with the saving of twenty-five per cent. in the copper used, which must be credited to the tri-phase transmission. So that while the low frequency adopted increased the efficiency of the plant, and favored many operations of the power plant, the first cost was not affected by the prophesied high cost of transformers, and all the advantages incident to both systems were obtained not only without an increase of the first cost, but a direct saving in the copper of the line. As the plant grew in size, many of the difficulties that had been expected in handling such an immense volume of electricity as was involved did not occur, and it was evident that the practical electricians attached to the great manufacturing establishments of electrical machinery had brought the appliances needed well up to the requirements of the new conditions. Every machine, every instrument needed, had to be contrived, not only to suit the size of the unit of 5000 horse power, but to meet the unknown effect of coupling so many great machines in parallel and distributing the current to establishments over which the attendants in the power-house have little or no control.

In thus referring to the utilization of power at Niagara Falls, I may seem to depart from the subject of transmission of energy, although the development of the industries described is intended to illustrate the direct results obtained by transmitted energy. The energy developed at the dynamos in the power-house, and existing as potential only while the dynamos are in motion, begins with an electro-magnetic force of 2200 volts, at which 5000 electrical horse power is transmitted by four cables, each 1¼″ in diameter, two cables for each phase of each dynamo, to the bus bars from which the current is distributed at from 2200 to 2000 volts (depending on distance) to points outside of the power-house within a radius of two miles. By means of step-up transformers 10,000 electric horse power of induced current of 11,000 volts can be carried to Buffalo by six cables, each ⅝″ in diameter, and capable of transmitting 10,000 electric horse power at the said voltage, or double that amount, at 22,000 volts, with a loss, based on Lord Kelvin's law of economy as to size of conductors.[1] You can better realize the idea of the size of the conductors when I tell you that from each turbine exerting over 5000 horse power a steel shaft 11″ in diameter is needed to drive each dynamo delivering 5000 electrical horse power, from which are carried the conductors of the sizes named. Four bus bars receive the current from five dynamos, the heaviest part of each bus bar being 3″ in diameter; *i.e.*, one 11″ steel shaft transmits kinetic energy of 5500 horse power; four 1¼″ cables transmit 5000 electric horse power energy of 2200 volts; three ⅝″ cables transmit 5000 electric horse power to Buffalo.

Besides the development of power at Niagara Falls, to which I have called your attention, numerous successful installations in various parts of our country could be referred to, and even in Europe we find the transmission of power by alternating current in existence, and, in fact, in some instances preceding in actual operation the starting of the plant at Niagara Falls; such installations being on a smaller scale required less time to construct them.

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[1] Lord Kelvin proposed, in determining the size of conductors for electricity, that the most economical area of conductor is that for which the annual cost of energy wasted is equal to the interest on that portion of the capital outlay which can be considered to be proportionate to the weight of the metal used; that is to say, the amount of copper and other details of the transmission line, the interest of which should equal that amount of energy at its cost of production that may be wasted. The lower the cost of the power generated the more energy may be wasted to advantage. If too large a conductor is installed for the purpose of decreasing the loss, the capital outlay will be needlessly great. If too small a conductor is adopted the waste of energy will be too great, hence the importance of a law that indicates what the economical loss should be. In applying this law there is more or less divergence of opinion as to what part of the capital outlay should be taken into consideration in determining the amount to be wasted. As, for instance, an underground conduit system may be built to accommodate a great increase of the number of conductors installed, or when a pole line is erected for a given amount of power, additional conductors may be supported on the same poles without any great increase of the cost due to enlarging the capacity of the transmitting line. The law, therefore, bears with most force on the metal if naked or the cable if the conductor is insulated.

The experiments of Mr. Tesla, which were directed toward the utilization of an alternate electric current of high frequency, and which were conducted in the interest of the Westinghouse Company, resulted in the issue of at least twenty-nine patents to cover the multiphase generation of electricity. The first of these patents was issued as early as 1888, and the last in 1891, and yet in 1893, so far as I am aware, there were no examples of the Tesla motors in commercial operation, for the reason that up to that time—and, in fact, not until 1895—the conditions had not been favorable to its development. As soon as there seemed to be a demand for their use, however, the manufacturers placed them on the market with as high an efficiency as the best direct-current motors, with this further advantage that is of the utmost importance: A direct-current motor and a direct-current dynamo are limited in their electro-motive force by the commutator necessary for their operation. The earliest alternating-current motors were what are known as synchronous motors; that is, motors that when started would run in step with the dynamo from which the current proceeded. These motors had no self-starting power, and involved many objectionable features that are not incident to polyphase motors of the induction type—in other words, what we know as the Tesla motor. In the first place, and as of vital importance, a Tesla motor can be wound to suit high voltage. Electricity at 2000 volts can be carried with absolute safety by properly insulated cables into buildings and applied directly to the motor without any live terminals; that is, without any part carrying current being exposed from which a dangerous shock of electricity can be obtained. They are all self-contained. They start with a powerful torque upon completing the circuit; that is, they start when the switch is closed and stop when the switch is open. Here is the possibility of an ideal electric motor, which is perfectly well understood by professional electricians, but about which the public have yet to be more thoroughly informed.

Though I have said that little was known about the alternating current in practice until lately, yet I have before me a copy of a letter written by Mr. L. B. Stillwell, one of our members, the Electrical Director of the Niagara Falls Power Company, when he was on the staff of the Westinghouse Company, dated May 11, 1893, in which he said: "I received yesterday from our engineer in charge of the installation at Pomona, Cal., a report of tests which he had been making, and I think you will be interested to learn that he has successfully transmitted 130 horse power over eighty-four miles of bare copper wire, supported upon our special insulators; the length of the circuits being eighty-four miles, the conditions are of course such as we should encounter in transmission over forty-two miles. The result was obtained by connecting up in series the respective circuits from the power plant to the town of Pomona and the city of San Bernardino. About 3200 insulators supported the conductor carrying 10,000 volts, and the fact that this was done without the slightest evidence of break-down was noteworthy and important." Since then on some of the Western lines 20,000 volts have been considered moderately low voltage, and 40,000 volts have been used successfully, and this all since the year in which bids were first asked for polyphase alternating-current dynamos under stated conditions by the Cataract Construction Company for the Niagara Falls Power Company at Niagara.

Mr. Edward D. Adams, the president of the Cataract Construction Company, to whom the above letter was addressed, was thoroughly alive to the advantage of the use of the alternating-current system in 1890, but in financiering the great development at Niagara Falls he held his mind open for truth, which he steadily pursued from the beginning, sustained by those interested with him, regardless of his own pecuniary interest and that of his personal friends.

My own interest in electricity began in early boyhood. As soon as I was able I followed the discoveries of Faraday and others experimentally, using instruments made by myself for the purpose. From 1846 to nearly 1849 I was engaged to superintend rolling iron and making the telegraph wire that was used in the first lines established west of the Allegheny Mountains. Keeping in touch with progress of the uses to which electricity has been applied, I have noted how powerfully the growing needs excite the inventive faculty of those engaged in any one branch of science; in general, also, the slow application to actual practice of knowledge given to the world by men seeking truth and laying the foundation of exact scientific methods. Our modern knowledge of thermodynamics does not express what was used to perfect the steam engine, as the best results and the greatest advance in the use of steam came before the students of thermo-dynamics gave us the modern text-book on the theory of steam. So it is with the transmission of energy by electricity: beyond the possession of useful knowledge, actual practice and the attempt to accomplish results will yet need many venturesome efforts.

In utilizing the power of Niagara Falls large units of power have been shown to be economical. A single dynamo built to yield 5000 electrical horse power has yielded 5600 electrical horse power without sign of overload. The wonderful efficiency of these machines, which have a loss of less than two and one-half per cent., has established the superiority of electrical transmission of power, and proved it to be more economical than any of the usual methods of transmission by material in motion; that is to say, by shafting, belting or compressed air, etc. All such methods involve great frictional loss. When a steam engine is attached directly to a dynamo, the electrical output of the dynamo, measured by modern instruments of precision, is known to be more reliable as an indication of the power produced by the combustion of a given amount of coal than any ordinary method of indicating the power of a steam engine to determine the horse power per pound of coal burned. Large factories, such as the Baldwin Locomotive Works, have recognized the economy of generating electricity by steam and transmitting it to the various machines or groups of machines in use, to which electric motors are applied, thus dispensing with long lines of shafting. How far electricity can be transmitted from the turbines at Niagara Falls with profit remains yet to be determined. The actual economy obtained by transmission to Buffalo, say a distance of twenty-two miles, is so much beyond what was predicated as possible in 1890, or even 1893, that no one can venture to say what will be forthcoming in the near future. With electricity it is very much as it was with railroads; fifteen miles per hour was thought to be a dangerous speed when locomotives began to supersede the stage coach. Those who travel now hope for an improvement that will lead to a higher rate of speed than we are now accustomed to. So it is with electricity by overhead lines of transmission. One thousand volts is no less dangerous than 11,000 volts on the Buffalo line, or 20,000 or 30,000 on some of the air lines in this country.

The question of underground transmission calls for a high quality of insulating material or method of preventing leakage, and of providing means of dissipating the heat that must result from any loss due to resistance in the conducting material used.

Copper is, of the available materials, the best conductor and the cheapest. The price of aluminum, however, owing to the cheap power used in its manufacture, has fallen from five dollars per pound to twenty-five cents per pound. Pure aluminum, properly alloyed with a metal that will increase its strength without decreasing its conducting quality, renders it possible at the present time for aluminum conductors to be offered at exactly the same price per mile as copper, with the added advantage of allowing the poles supporting the line to be placed much farther apart, thus using fewer insulators and decreasing the cost of the line; also insuring more economy in transmission, as there is less leakage, due to the diminished number of supports, all of which will be weak points in the transmitting system. The increased area required for the lighter metal, resulting in a larger radiating surface, is favorable also to the dissipation of the heat engendered by the resistance in the line, as whatever energy is lost in such transmission assumes the form of heat energy.

What can this or any other learned Society do to help in the promotion of the knowledge of electricity applied to the use of man? It is a matter of great importance to those interested in the work of this Society that they recognize the necessity of exerting themselves to carry out the intent of its founder in promoting useful knowledge. We must try to induce the members and others to make use of the advantages that the Society possesses in disseminating useful knowledge through its publications, and to make this building and these rooms the place for the discussion of subjects of practical as well as theoretical importance in the same direction, on the lines so earnestly followed by its founder, who tried to bring together representative men of varied attainments and to have them submit papers for discussion.

In my efforts to interest members in our work in the direction of the subject of this discourse, and to have them submit papers for discussion, I have been met, first, with the excuse of want of time for the preparation of matter; second, the desire of most specialists to contribute to the societies devoted to their specialties; third, to the fact that there are so many periodicals for each special department of science ready and eager to obtain, even to pay for, copy, and in the case of electricity as applied to the service of man many of the professors of physics in colleges, specialists besides those on the staffs of the great manufacturing companies, are retained in the interest of such companies, and in some cases are even discouraged from making public what for a time can be used to advantage in a commercial way and classed among the trade secrets. I speak knowingly on this subject, for the first question that was asked me in 1889, before I was solicited to report on the subject of transmission of power by electricity, was whether I was retained in the interest of any electric company. The fact that patent litigation has played so important a part in the development of electricity is also to be taken into account when an effort is made to awaken debate on subjects that should be of special interest in the Society founded by the early electrician, Benjamin Franklin. Many men are loath to commit themselves in debate that may in a short time be taken hold of by patent attorneys. The commercial aspect of scientific advance is too important to be ignored; we must therefore, as members of the American Philosophical Society, as far as we can, induce others to assist in the work of the Society by showing a willingness to take an active part in the meetings that are held in this room, and by early publication of matter submitted give precedent in publication to those who lay claims to priority of discovery.

Stated Meeting, April 21, 1899.

Vice-President SELLERS in the Chair.

Present, 17 members.

The Curators announced that, in accordance with a resolution of the Society, the Carthaginian tombstone in its possession had been photographed, and exhibited a blue print of same (see accompanying figure, page 72).

The death of Sir Monier-Monier Williams, of London, England, April 11, 1899, who was elected a member December 17, 1886, was announced.

Dr. Stellwagen made a verbal communication to the Society in regard to a tombstone presented by Commodore Stellwagen,